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# An Integrated Approach to Educating Professionals for Careers in Innovation

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***There is an increasing realization of the difficulties professionals in innovation-related jobs face in bridging the interface of technology and business. Further, the use of technology for business innovation increasingly involves technologies transferred across businesses or from universities to industry, either through licensing or engagement of entrepreneurial enterprises, requiring coordination of efforts by inventors, business, and legal professionals. Recent studies in technology entrepreneurship recommend integrated approaches to educating students to operate in this space. We discuss the benefits and challenges of integrated approaches to graduate education in technology entrepreneurship in the context of an NSF-sponsored program that teams science and engineering PhD students with law and MBA students. The curriculum focuses on the technical, legal, and business issues involved with moving fundamental research to the marketplace. We draw on program assessment data, which includes pre- and post-surveys and a control group. We find significant and positive effects of the program on student perceptions of the multidisciplinary capabilities needed to operate in a technological business environment.***

There is an increasing realization of the difficulties professionals in innovation-related jobs face in bridging the interface of technology and business (Greene, Hardy, & Smith, 1995). The Industrial Research Institute's Research and Development (R&D) survey routinely lists "growing business through innovation," "improving knowledge management," and "integration of R&D with business strategy," among the top-10 problems in R&D (Industrial Research Institute, 2007). Furthermore, the use of technology for business innovation increasingly involves technologies transferred across businesses or from universities to industry, either through licensing or engagement of entrepreneurial enterprises, requiring coordination of efforts by inventors, business, and legal professionals (Jensen & Thursby, 2001; Zucker, Darby, & Armstrong, 2002; Zucker, Darby, Furner, Liu, & Ma, 2006).

Whether innovation involves coordination within or between institutions, two points are clear. First, technological innovation is not simply invention, but rather a process that includes all the steps from the decision to conduct research to identification of opportunities and paths for commercial application and business growth (Schumpeter, 1939). Thus while scientific discovery is central, it is only one piece of a complex process involving business, legal, and regulatory decisions. Second, it requires the expertise of a variety of professionals: (1) scientists or engineers engaged in invention, (2) corporate or technology business experts who evaluate and develop business models for commercialization; and (3) attorneys involved in intellectual property protection. Thus innovation is implicitly a team activity, which relies on participants understanding at least some aspects of each others' expertise as well as effective communication across areas.[1]

Recent studies in technology entrepreneurship recommend integrated approaches to educating students to operate in this space (Kingon, Thomas, Markham, Aiman-Smith, & Debo, 2001; Kingon, Markham, Thomas, & Debo, 2002; Thursby, 2005; Sager, Fernandez, & Thursby, 2006; Barr, Baker, Markham, & Kingon, 2008). These studies focus on graduate education since the degree requirements are typically either research degrees, such as the PhD, or professional degrees, such as the MBA or JD in the case of business or law. Integrated programs span disciplinary lines, but more important, they combine coursework on fundamental concepts and processes with real team-based projects on technology commercialization. The argument for real commercialization projects is that much of the knowledge needed for success in entrepreneurship, in general, and technology development, in particular, is tacit, and therefore, difficult to learn without "doing" (Polyani, 1967; Aronsson, 2004; Honig, 2004). The more formal coursework introduces students to principles that allow them to generalize from the specific results of the team projects.

We discuss the benefits and challenges of integrated approaches to graduate education in technology entrepreneurship in the context of one such program, the National Science Foundation (NSF) sponsored program, "Technological Innovation: Generating Economic Results" (TI:GER®) at Georgia Institute of Technology and Emory University. This program brings PhD students in science and engineering from Georgia Tech together with Georgia Tech MBA students and Emory JD students to examine issues related to the commercial potential of the PhD students' thesis research. Supported by a curriculum that focuses on the technical, legal, and business issues involved with moving fundamental research to the marketplace, the program leverages PhD research while creating an on-campus internship in technology commercialization for the MBA and JD students. As we will argue, this integrative approach not only addresses the need for these students to understand issues in technology commercialization, but also can enhance the research agenda itself.

While there are a number of high-tech entrepreneurship programs, this one is unique in its breadth (spanning science, engineering, business, and law) and its upstream nature—that is, the fact that its experiential component organizes teams to examine commercialization issues early on, *as* the research is being conducted (Thursby, 2005). More important, because the program has been federally funded, it included an external assessment component from its inception. The assessment plan is quasi-experimental, including pre- and posttests, and for one cohort of students, data are available for a control group.

Gorman et al. (1997), Storey (2000), and Rideout and Gray (2008) emphasize that despite an ever-increasing interest in entrepreneurship education, there is little empirical research on the effectiveness of various approaches. To our knowledge, no existing empirical study focuses on high-tech entrepreneurship programs at the graduate level. We contribute by providing a discussion of the need for an integrated approach in such programs and a quasi-experimental empirical analysis of TI:GER, along with a discussion of challenges and lessons learned from implementing the program.

In the next section we discuss the arguments for an integrated approach to graduate education in technological innovation and entrepreneurship. Subsequent sections describe the TI:GER program, pedagogical approach and curriculum, assessment design and analysis, and program challenges. In concluding, we discuss the implications for further research.

## THE NEED FOR AN INTEGRATED APPROACH

Introducing entrepreneurship education to graduate programs is challenging because they are typically highly structured and allow little latitude for courses outside the primary discipline. This is particularly true in doctoral programs where research training is the primary focus. We argue that while standard courses have little appeal, integrative programs in which students "add on" experiential entrepreneurship modules that complement their core in-depth degree work can add value. We make this argument both in the context of students pursuing research degrees in science and engineering and students pursuing professional degrees in business and law.

### Science and Engineering PhD Students

The majority of U.S. PhD scientists and engineers pursue industrial careers, with placement varying from corporate labs to small, high-tech companies (National Science Board, 2006). Many are quickly drawn into management roles in research and de-

[1] In principle a single entrepreneur could attempt to handle all areas, as in Lazear's (2004) jack-of-all trades, but studies of high-tech entrepreneurship (Cooper & Daily, 1997, and Cooper, Woo, & Dunkelberg, 1988) suggest that balanced teams improve success.

velopment and find the transition difficult (Greene et al., 1995). They come from an environment driven by pure or applied-disciplinary research into a workplace driven by interdisciplinary market-driven research. They work with a diverse pool of coworkers, and in order to exercise a leadership role, they must understand complexities of the innovation process beyond their scientific training. A study by the National Academy's Government–University–Industry Research Roundtable (GUIRR) indicates that while U.S.-educated scientists and engineers are well trained to conduct research, they lack skills in management, communication, and team-based problem solving that are critical to decision making in innovation-related careers (GUIRR, 1991; Armstrong, 1994; COSEPUP, 1995). The study further emphasizes the need to address these deficiencies without sacrificing specialized and in-depth technical training.

Even for students who intend to pursue academic careers, there is an increasing need to understand when their research has commercial potential. This is particularly true in the life sciences, where the lines between basic and applied research have become blurred, so that many research topics lie in what is known as Pasteur's Quadrant, where basic or fundamental research has direct (albeit with significant subsequent testing and development) applicability for solving industrial problems (Stokes, 1997).[2] The problem is that it is often difficult for researchers to recognize applications of their work (Shane, 2000; Thursby & Thursby, 2002). Regardless of their career goals, it can be argued that students whose research lies in Pasteur's Quadrant need to be able to recognize when the research has commercial potential. Indeed, the first step in the direct transfer of academic research to industry is the disclosure of inventions believed to have commercial potential. Recent empirical evidence on disclosure in U.S. universities suggests that only a fraction of inventions with commercial potential are disclosed (Jensen, Thursby, & Thursby, 2003). This is hardly surprising since most academic research is sufficiently basic that the translation of results into downstream applications is not obvious early on. In fact, many university inventions have a variety of applications (Shane, 2000).

Thus, regardless of career goals, one can argue that science and engineering PhD students can benefit from education that improves their ability to recognize potential market applications of their work. The problem is that it is important not to divert them from their doctoral research. This argues against their enrolling in traditional, generic business classes, and *for* introducing entrepreneurship experiential elements that complement their research.

### Students in Professional Degree Programs: MBA and JD

Similarly, business and law students with career goals in technology or innovation management need to understand the interface of business, law, and technology. This is surely the case for business students with career aspirations in companies that either conduct research in-house or insource R&D. While there is no need for them to understand enough science or engineering to conduct research, they need to understand various aspects of how a technology works in order to predict cost, valuation, and other business implications of an invention. An understanding of how to protect the intellectual property (IP) is an integral part of business strategy for developing an invention (Teece, 1986).

There is an equally compelling case for law students to have a working knowledge of scientific and business principles. An important problem facing the legal profession today is that many cases and decisions require knowledge of scientific principles (Breyer, 1998, 2000). Many patent infringement cases hinge more on scientific than market-related issues. Scientific knowledge is even more critical for those interested in becoming patent examiners, since they must judge the novelty and nonobviousness of inventions (Bagley 2003a,b, 2001). Finally, those interested in careers as corporate legal counsel need to understand the business ramifications of various approaches to protecting intellectual property (IP). For example IP is often the basis of the competitive advantage of product portfolios. TI:GER law students learn IP can be a critical component of firm exit strategies such as IPOs, acquisitions, and alliances. Further, they learn how to protect the firm's IP assets while facilitating its business and research objectives. Long-term business needs must be balanced with necessary legal guidelines for relevant risks to be evaluated by the senior business leaders. Something typically not taught in law school courses, but important for these students to understand, is the variation in effectiveness of different mechanisms for protecting IP across industries (Cohen, Nelson, & Walsh, 2000).

Just as the GUIRR and COSEPUP studies reported a need for doctoral students to gain experi-

[2] For further discussion of Pasteur's Quadrant as it relates to academic research, see Thursby and Thursby (2009).

ence in team-based problem solving, there is a need for both MBA and JD students with innovation-related career objectives to have experience working with scientists and engineers (as well as with each other). Exposure to PhD students in science and engineering requires professional students to figure out how to talk to researchers (and the importance of asking the right questions along the way), to understand their motivations; to understand the nature of the research process with its dead ends, stops and starts; and to understand how laws and business organizations impact whether that research reaches its full potential (Fleming, Quinn, & Thursby, 2005a,b).

Finally, it is important to recognize that while cross-functional teams are often employed in industry to improve innovation, their performance is often reported to be less than anticipated (Perry-Smith & Vincent, 2008). Why this is the case and ways to improve performance is a burgeoning research area (Gerwin & Barrowman, 2002; Randel & Jaussi, 2003). To this point, we suggest that students with multidisciplinary team experience in their graduate education may well have a competitive advantage early in their careers.

## TI:GER PROGRAM GOALS AND STRUCTURE

### Overview and Program Goals

Formally, TI:GER is a 2-year certificate program that focuses on the technical, legal, and business issues involved with moving fundamental research to the marketplace. Students participate in the program while still continuing as full-time students in their respective traditional degree programs. TI:GER courses and projects complement but don't replace the core elements of the JD, MBA, and PhD programs.

The program has four goals, two primarily aimed at career preparation and two research goals. The first is to graduate technically proficient science and engineering PhDs with the skills and multidisciplinary perspective needed to succeed in innovation-related careers. Throughout the program, science and engineering doctoral students collaborate with MBA and JD students to examine technical, business, and legal factors that will influence potential market applications of the PhD students' thesis research. The idea is to involve these students in collaborative, multidisciplinary projects of mutual benefit without sacrificing the rigor and in-depth education of their respective degree programs. Similar to this, the second educational goal is to expose MBA and JD students with career goals in technology, R&D management, or patent or intellectual property law to the challenges in fundamental research and its commercialization.

The last two goals pertain to research. The goals for the science and engineering students are to produce thesis research of scientific merit *and* market relevance. The idea is for doctoral students to consider market implications of thesis research early on, allowing them to refine their research ideas in light of market, legal, and regulatory issues involved in potential applications researched by the MBA and JD students. The last goal involves management and economics PhD students who serve as teaching assistants in the program with the aim of preparing them both to teach in multidisciplinary programs and to conduct research on innovation.

In keeping with the focus of this special journal issue, we concentrate on program elements and assessment as they relate to attainment of the first two educational goals.

### The Team Model

Central to the program are team-based projects centered on the PhD students' research. Note the intent is not to divert the PhD students from fundamental research, but to expand their knowledge of the legal and management tools used by businesses to capture value from research and development. Similar to this, the MBA and JD students are not diverted from their regular program, but gain hands-on, clinical experience in a technical research environment. Thus, all the students are given firsthand experience in the challenges of commercialization, multidisciplinary teamwork, and behavioral aspects of project management.

Figure 1 illustrates the composition of TI:GER teams as well as the nature of team collaboration. Team participants include law, economics, and management faculty, as well as the PhD, MBA, and JD students, along with a program director with industry experience in commercialization, and economics and management doctoral students who serve as teaching assistants. The participation of practicing professionals and industry mentors is a key component for integration of realistic industrial perspectives into the curriculum. Each team has four members: a PhD student, an MBA student, and two JD students (one specializing in a patent law track and the other specializing in technology law). This section presents a stylized view of team collaboration over the 2-year period.

The ideal is for PhD students to enter the program as they are beginning their thesis research. The best way to understand this collaborative

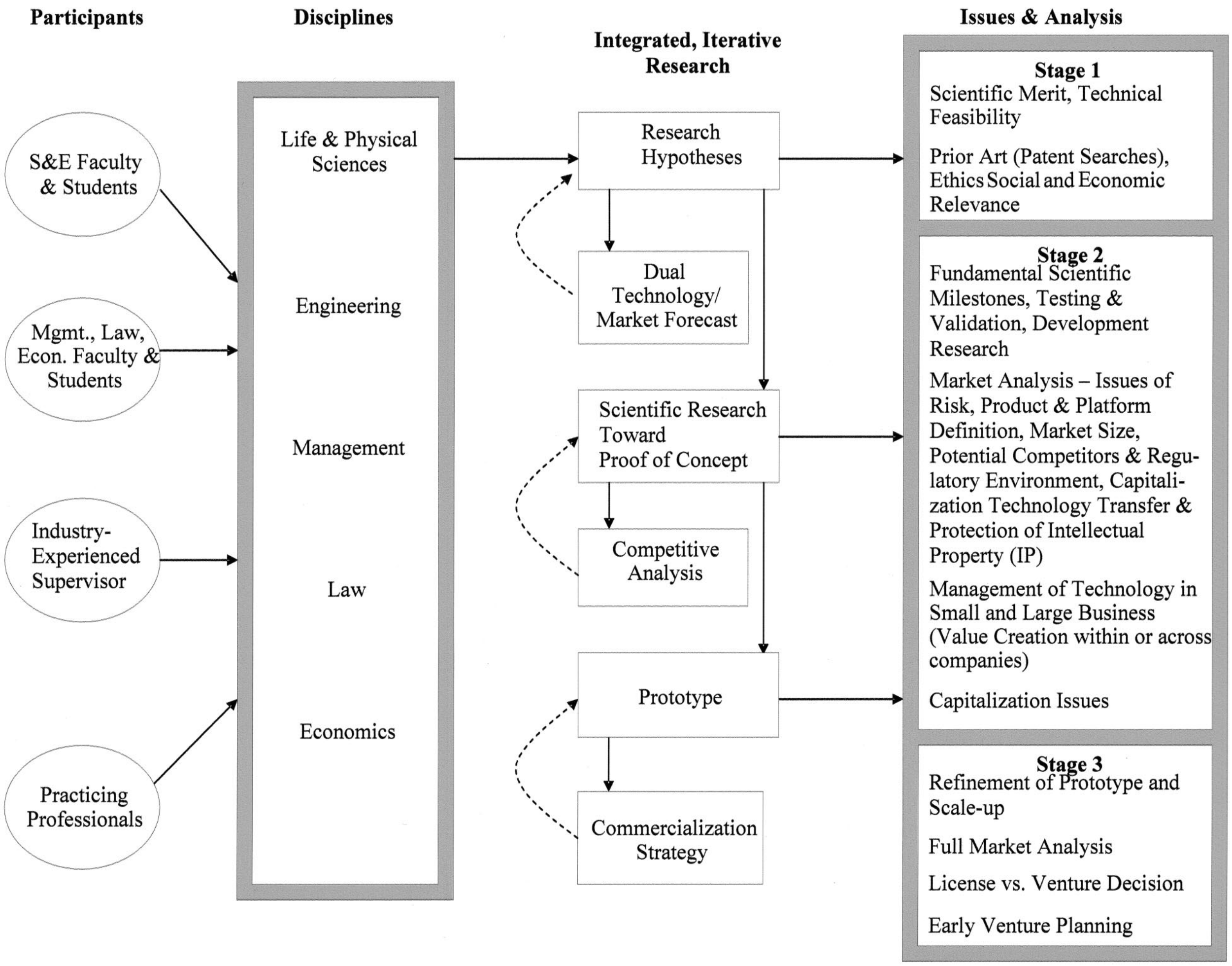


**FIGURE 1**
**TI:GER Collaboration Model**

model is to compare it with traditional science and engineering research in which students and advisors consider primarily technical issues in determining the students' research agenda. Initially the students formulate hypotheses based on the current knowledge base and potential contributions to the science or engineering literatures. As the research proceeds toward proof of concept, the focus turns to testing and validation, and once a lab scale prototype is developed, issues of scale up become important.

In TI:GER teams, business and legal issues are considered as early as the hypothesis formation stage. At this stage, the science and engineering students' primary responsibility is to communicate the technical challenges of their research as well as its expected scientific merit. Juris doctorate students are responsible for directing patent searches and identifying prior art which, of course, is contingent on effective communication by the PhD students. MBA students take primary responsibility for market research. For some thesis topics, market research is well defined, but for others the science and engineering research may lead to platform technologies capable of impacting a variety of markets that cannot be identified *ex ante*. Initial forecasts for most topics therefore consider a number of emerging markets in different industries. Teams are encouraged to consider two to four industries or markets before selecting one for initial focus. As research progresses toward proof of concept and lab scale prototype, the analysis turns to the nature of competition in relevant industries as well as practical issues, such as how basic research is transferred to industry. Business issues addressed may include manufacturing feasibility, cost, sales, recycling and other ethical issues, as well as strategies to facilitate industrial application (e.g., exclusive or nonexclusive license, start-up ventures). Legal issues such as regulations and approvals affecting market potential and intellectual property protection are also thoroughly covered in due course. In some cases students are interested in commercializing the research through a start-up venture, and the legal and financial aspects of business organization become important.

## Program Structure

As noted above, TI:GER is a 2-year program. The science and engineering students are admitted as they begin their thesis research, which for most students is the second or third year of their PhD programs. The MBA is a 2-year degree, so that students are recruited as a part of the regular MBA recruitment process. The JD is a 3-year degree, and students enter the TI:GER program in the beginning of their second year. Figure 2 describes the curriculum.

In their first year, students take Fundamentals of Innovation I and II, which are open only to TI:GER students and cover a variety of topics in a typical sequence of activities in technology commercialization. Topics in the first semester include issues in university–industry technology transfer, an introduction to experimental research methods in science and engineering, identification of entrepreneurial opportunities in technological environments, the role of balanced teams in technology commercialization, legal ways to protect intellectual property (including marks and secrets as well as patents), and how their effectiveness varies across industrial sectors as well as an introduction to capabilities needed to succeed in particular industries. Early in the semester, team selection and team-building exercises are a major focus. The major semester deliverables are (a) an intellectual property assignment related to the doctoral students' research, and (b) a preliminary industry analysis relevant to commercial application of that research. The intellectual property assignment includes a disclosure of an invention the PhD student expects to result from his/her research as well as a search of prior art (all publicly available information related to the invention's claims of originality, which includes patented and nonpatented publications). The industry analysis focuses on an industrial application of the research including a justification of the chosen industry as the best initial application of the work. The analysis is based on projected market size and growth, industry trends using tools such as the political economic

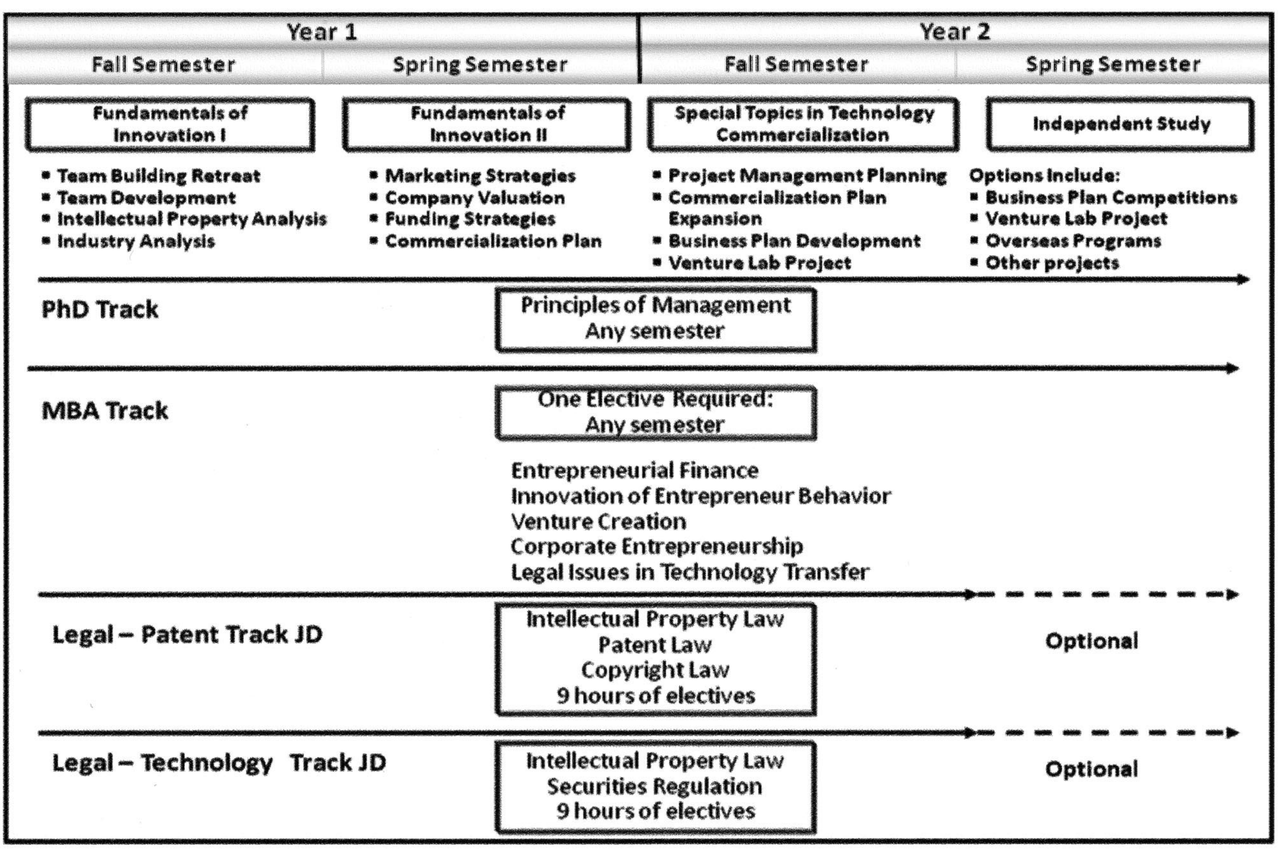


**FIGURE 2**
**TI:GER Curriculum**

social technological (PEST) model, and an analysis of the competition using Porter's five forces model.

The second semester covers such topics as licensing versus venturing, market analysis, entrepreneurial finance (including a real-options framework), and business association (and securities) law. The key team deliverable is a commercialization plan evaluating alternative strategies for getting research into the marketplace. The plan covers the market opportunity, value proposition, potential target customers, and the technology development cycle. In addition to an industry analysis (which often changes significantly from that developed in the first semester) the commercialization plan provides a product description, recommendations for protection of the intellectual property and the alternatives considered, competitive advantages provided by the technology, potential customers and partners in the market, and financial feasibility, which can include a valuation using both discounted cash flow and real-option pricing models. Toward the end of the semester a summary presentation of the commercialization plan is made to an audience including members of the TI:GER industry advisory board, industry mentors (including entrepreneurs and venture investors), and university faculty members.

Various faculty members from Georgia Tech, including the College of Management, and the Emory School of Law teach the TI:GER innovation course modules. Outside speakers include the leadership of the Georgia Tech Office of Technology Licensing, patent and technology attorneys, venture capitalists, and technology entrepreneurs.

The core 2nd year course, Topics in Technology Commercialization, is a capstone structured much like a consulting course. Teams evaluate business opportunities and help develop business plans and strategic licensing plans for early-stage technologies being developed in the Georgia Tech incubator. This work gives students more hands-on experience, not only in the process of technology commercialization, but also in consulting with small businesses. Additionally, depending on the progress (or lack thereof) of the PhD student's research, students build on the work in the first year by either developing a full business plan for technology based on this research, writing an SBIR application, or writing a detailed case study of their team experience.

As shown in Figure 2, the science and engineering students are required to take a course in principles of management for engineers in addition to the core TI:GER courses. All PhD students at Georgia Tech must specify a minor, and TI:GER science and engineering students can use the TI:GER courses for the minor. The MBA students are required to take a series of program-relevant electives, such as Entrepreneurial Finance, Legal Issues in Technology Transfer, or Organization Entrepreneurship. Similarly, the JD students are required to take program-relevant electives such as Business Associations, Patent Law, Copyright Law, Trademark Law, and Corporate Finance. The TI:GER experience plus these courses will provide them with a degree concentration in either Intellectual Property or Technology Law.

## PROGRAM STATISTICS AND ASSESSMENT

Since 2002, 190 students have participated in the program. Forty eight were PhD students in science or engineering, 85 were JD students, 47 were MBA students, and 10 were PhD students in either management or economics who served as teaching assistants. Of the 48 students from science and engineering, 34% came from bioengineering or biomedical engineering, 22% came from mechanical engineering, 21% from electrical and computer engineering, 8% from chemistry or chemical engineering, and 15% came from other disciplines such as physics, computer science, material science, or industrial engineering. Research topics are quite varied. Examples include circuit design for concurrent search for many patterns in large datasets, use of nuclear magnetic resonance in treating insulin-dependent diabetes, use of quantum dots for early cancer detection, construction of micro- and nanostructures for cell cultures, characterization of shape memory polymers, structure–function relationships of articular cartilage in shear, and high-speed digital packaging and mixed signal system design.

From its inception, the program included an assessment plan administered by an educational assessment expert not affiliated with either the TI:GER program or the College of Management (the organizational home of the program). Assessment goals were both formative and summative, so that student feedback and performance could be used for program improvement. As reported in Fleming et al. (2005b), initial assessment efforts relied heavily on focus groups of students by program area and led to a number of program revisions, which we discuss in the next section on program challenges. In addition, with assistance of industrial advisors and TI:GER faculty, the assessment coordinator developed pre- and postsurveys to assess student perceptions of their skills or multidisciplinary competencies on entry and exit. Data from these surveys allow us to evaluate student learning effects across degree programs and as compared with a matched control group. Our data are for student cohorts entering in 2004, 2005, and 2006.

Three cohorts (7 teams each) representing 84 students completed the TI:GER program during the time of this study period. In addition to those students in the program, in 2004 a control group was established. The control group was constructed by obtaining the list of students in each degree program and cohort of TI:GER entrants and then randomly selecting participants for the control. For example, in a year in which two PhD students were from mechanical engineering, we obtained the names and contact information for all other PhD students in mechanical engineering that entered Georgia Tech in the same year, then we randomly selected a group of four to contact. These students were given pre- and postsurveys and were offered a monetary reward for participation. Figure 3 below gives the distribution of students in the 2004–2006 cohorts plus the control by program area and year starting the program.

As previously noted, the multidisciplinary team approach is a key element of the program. Teamwork is also the students' most commonly mentioned benefit of the program. For example in the exit survey the students are asked, "What were the three most important aspects of your TI:GER experience?" Of the 71 survey respondents, 51 gave at least one item in the space provided. Together 118 answers to this question were submitted (an average of 2.3 items per respondent to this question). Seventy-two percent of the respondents listed "team" or "teamwork" as one of the most important aspects. Figure 4 provides the distribution of these answers.

In addition, the students were asked, "Overall, to what extent do you feel the interdisciplinary team experience was useful to you?" Fifty-five percent of the 70 respondents answered the team experience was very useful (84% said very or moderately useful). We then divided the responses by field of study. Of the 18 PhD respondents, 15 of them answered that the interdisciplinary team experience was very useful. Figure 5 shows these results by JD, MBA, and PhD.

To assess the extent to which the TI:GER courses and team experience contribute to student awareness of commercialization issues at the interface of the three program areas, the students were asked on both the pre- and postsurvey to provide a self-assessment of their capability or competency in each of 14 skills listed in Table 1. Capabilities were ranked on a 4-point scale, where 1 is *not capable*, 2 is *minimally capable*, 3 is *moderately capable*, and 4 is *extremely capable*.

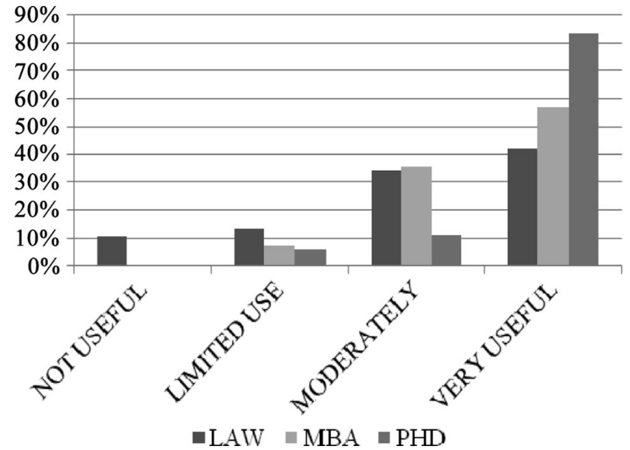


**FIGURE 4**
**Most Important Aspects of TI:GER**

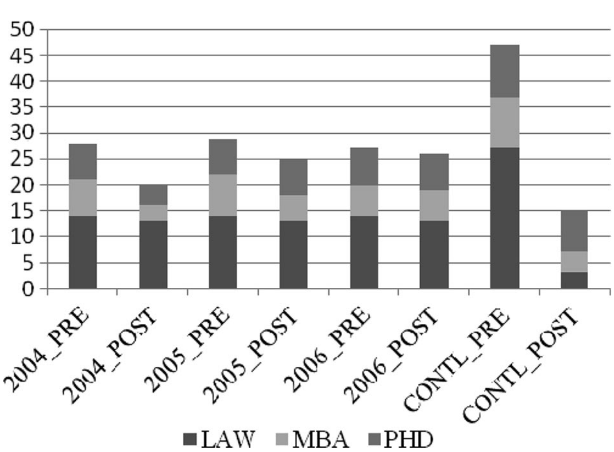


**FIGURE 3**
**Students Pre & Post TI:GER Program**

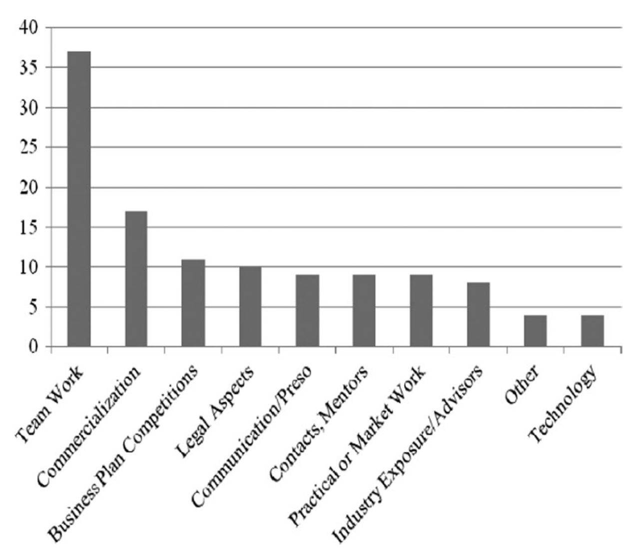


**FIGURE 5**
**Team Experience Usefulness**

**TABLE 1**
**Survey Question: Rate the Extent You Feel Capable of Performing Each Skill**

| Question | Shorthand | JD | MBA | PHD |
|---|---|---|---|---|
| Assess the business impact of relevant legal decisions | ASSESS BUS IMPACT LEGAL | 0.573*** | 0.833*** | 1.087*** |
| Assess legal implications of various business decisions | ASSESS LEGAL EFECT BUS DEC | 0.511*** | 1.047*** | 0.913*** |
| Develop strategic plan to protect intellectual assets | PLAN PROTECT IP | 0.817*** | 0.905*** | 1.243*** |
| Understand competitive advantage of appropriate intellectual property protection | COMP ADV IP PROTECT | 0.586*** | 1.190*** | 0.976*** |
| Identify the regulatory approval paths needed for a business opportunity | ID REG NEED | 0.509*** | 1.476*** | 0.500* |
| Identify breadth of financial investments sources for technology commercialization | ID FIN SOURCE | 0.374* | 1.262*** | 1.024*** |
| Identify market viability for an invention | ID MKT VIABLE | 0.538*** | 0.762*** | 1.103*** |
| Identify resources necessary to succeed in a particular industry | ID RES SUCCESS | 0.269 | 0.762*** | 0.651*** |
| Identify business opportunities | ID BUS OPPS | 0.029 | 0.524* | 0.333** |
| Evaluate opportunities & threats of the competitive environment | EVAL OPPS & THREAT | 0.280* | 0.714*** | 0.603*** |
| Evaluate business risks | EVAL BUS RISKS | 0.273 | 0.571** | 0.770*** |
| Identify career opportunities in technology commercialization | ID CAR OPPS | 0.229 | 0.619** | 0.865*** |
| Write high-quality technical documents | WRITE TECH DOCS | 0.407* | 0.619** | 0.341* |
| Recognize need for quality control in technology commercialization | QUAL CONTROL TECHNOLOGY | 0.127 | 0.715*** | −0.065 |

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

The list was developed in collaboration with TI:GER industry advisors who provided input on the competencies they considered essential for any professional involved in technology commercialization. The TI:GER faculty then mapped these competencies to the program goals in each discipline of providing students with the multidisciplinary perspective needed for technology commercialization. The first five items in Table 1 explicitly acknowledge the necessity of knowledge across the disciplines. The next six refer to essential knowledge of business issues; although for MBA students this does not reflect cross-disciplinary learning, it clearly does for PhD and JD students. There are only two technical capabilities, one on writing technical documents (which could include patent drafting) and the other dealing with understanding the importance of quality control in commercialization. This is because the program is not designed to provide the non-PhD students with research tools, but rather for them to gain experience working in teams with scientists and engineers and understanding commercialization aspects of technology.

For each capability, the last column in Table 1 gives the average difference between student ratings on exit and entry by field in the program. Notice that the PhD students felt they had significant gains for all capabilities except one (the need for quality control). This is not entirely surprising since we would expect them to have a base level of understanding from their own degree program. The MBA students felt they had significant gains in all areas, while the JD students felt they had significantly improved in 9 of the 14 capabilities. The areas in which the JD students perceived no significant gain are ones which are typically more business and/or technically related functions, rather than a blend of law and business.

## METHODS

### Statistics Approach

To examine the effect of the program on perceived capabilities, we take an econometric approach that allows us to use controls in the analysis. For each of the 14 skills, we consider separate regressions. These regressions are analyzed using two samples. In the first we include all observations. That is, we include respondents from all study areas (PhD, MBA, and JD) from both the control and the TI:GER program samples. In the second regressions we confine attention to the program sample respondents from all fields. This allows us to consider differential effects by field from participation in the program. The dependent variables take on the ordered values 1 to 4, thus ordered logit models are used. The independent variables are all indicator variables or interactions of indicator variables defined as follows:

- EXIT = 1 if the observation is a response in the exit period, 0 otherwise
- LAW = 1 if the respondent is a JD law student, 0 otherwise
- MBA = 1 if the respondent is a MBA student, 0 otherwise
- CONTROL = 1 if the respondent is in the control sample, 0 otherwise

- COHORT5 if the respondent entered the sample in 2005, 0 otherwise
- COHORT6 if the respondent entered the sample in 2006, 0 otherwise
- EXIT_LAW is the interaction of EXIT and LAW
- EXIT_MBA is the interaction of EXIT and MBA
- EXIT_CONTROL is the interaction of EXIT and CONTROL
- EXIT_COHORT5 is the interaction of EXIT and COHORT5
- EXIT_COHORT6 is the interaction of EXIT and COHORT6

For respondent $i$ the linear portion of the ordered logit model when all observations are included; that is, the "full sample," is

$$\beta_X \mathrm{EXIT}_i + \beta_L \mathrm{LAW}_i + \beta_M \mathrm{MBA}_i + \beta_C \mathrm{CONTROL}_i + \beta_5 \mathrm{COHORT5}_i + \beta_6 \mathrm{COHORT6}_i + \beta_{XL} \mathrm{EXIT\_LAW}_i + \beta_{XM} \mathrm{EXIT\_MBA}_i + \beta_{XC} \mathrm{EXIT\_CONTROL}_i + \beta_{X5} \mathrm{EXIT\_COHORT5}_i + \beta_{X6} \mathrm{EXIT\_COHORT6}_i.$$

With respect to these regressions, the hypotheses of interest often can be answered by reference to a single coefficient, but in some cases reference must be made to combinations of coefficients. In Table 2 are the hypotheses with respect to the full sample along with the associated null hypotheses. For example, if we wish to test whether the control and program samples gave different answers to a question on entry to the sample; that is, we want to test whether there is nonrandom selection into the program, then row A gives the relevant values of the indicator variables and the associated null hypothesis for the regression coefficients. If the null is accepted, then we accept that each group provided insignificantly different answers. In the final column of the table is our shorthand notation for the null hypothesis. Rows B, C, and D are different approaches to measuring the treatment effect of the program.

The use of interactions allows tests of whether treatment effects differ by cohort and type of student, thus increasing the generality of our analysis. For example, we find (see below) that often there are significantly different treatment effects in the TI:GER participant sample on exit law and PhD students but that there are few significant differences between MBA and PhD students. Also, if we had used the scores as the dependent variable in a linear regression model instead of an ordered probit model, then our regression would have been the standard analysis of variance wherein differences in means between groups would be recorded in sets of coefficients. The ordered model correctly treats the scores as ordinal rather than cardinal numbers.

Finally, when the control sample is dropped the linear portion is given by

$$\beta_X \mathrm{EXIT}_i + \beta_L \mathrm{LAW}_i + \beta_M \mathrm{MBA}_i + \beta_5 \mathrm{COHORT5}_i + \beta_6 \mathrm{COHORT6}_i + \beta_{XL} \mathrm{EXIT\_LAW}_i + \beta_{XM} \mathrm{EXIT\_MBA}_i + \beta_{X5} \mathrm{EXIT\_COHORT5}_i + \beta_{X6} \mathrm{EXIT\_COHORT6}_i.$$

Table 3 gives the relevant null hypotheses for this sample.

## Results

For the full sample, one hypothesis of particular interest is whether there is a difference between the control and program respondents on entry to the program. This is Hypothesis A in Table 2. As shown in Table 4 row CONTROL, for 9 of the 14 skills there is no significant difference on entry; for the remaining cases, two are significantly different at 10% and three at 5%. Thus there is some evidence (albeit weak) that there is nonrandom selection. However, on exit there are significant differences in responses between control and program responses for 10 of the 14 (row C_P_EXIT in Table 4), and in

**TABLE 2**
**Null Hypotheses for the Full Sample**

| | Test of No Differences | Indicator Values | Null Hypothesis | Shorthand |
|---|---|---|---|---|
| A | Control *vs.* program at entry | EXIT = 0 & CONTROL = 1 *Vs.* EXIT = 0 & CONTROL = 0 | $\beta_C = 0$ | CONTROL |
| B | Control *vs.* program at exit | EXIT = 1 & CONTROL = 1 *Vs.* EXIT = 1 & CONTROL = 0 | $\beta_C + \beta_{XC} = 0$ | C_P_EXIT |
| C | Control at entry *vs.* exit | EXIT = 0 & CONTROL = 1 *Vs.* EXIT = 1 & CONTROL = 1 | $\beta_X + \beta_{XC} = 0$ | C_ENTRY_EXIT |
| D | Program at entry *vs.* exit | EXIT = 0 & CONTROL = 0 *Vs.* EXIT = 1 & CONTROL = 0 | $\beta_X = 0$ | EXIT |
| E | Control change *vs.* program change | Row C minus row D | $\beta_{XC} = 0$ | EXIT_CONTROL |

**TABLE 3**
**Null Hypotheses for the Program Sample**

| | Test of No Differences | Indicator Values | Null Hypothesis | Shorthand |
|---|---|---|---|---|
| A | Law *vs.* PhD at exit | EXIT = 1 & LAW = 1 & MBA = 0 *Vs.* EXIT = 1 & LAW = 0 & MBA = 0 | $\beta_L + \beta_{XL} = 0$ | L_P_EXIT |
| B | Law *vs.* PhD at entry | EXIT = 0 & LAW = 1 & MBA = 0 *Vs.* EXIT = 0 & LAW = 0 & MBA = 0 | $\beta_L = 0$ | L_P_ENTRY |
| C | Law change *minus* PhD change | Row A minus Row B | $\beta_{XL} = 0$ | L_P_DIFF |
| D | MBA *vs.* PhD at exit | EXIT = 1 & LAW = 0 & MBA = 1 *Vs.* EXIT = 1 & LAW = 0 & MBA = 0 | $\beta_M + \beta_{XM} = 0$ | M_P_EXIT |
| E | MBA *vs.* PhD at entry | EXIT = 0 & LAW = 0 & MBA = 1 *Vs.* EXIT = 0 & LAW = 0 & MBA = 0 | $\beta_M = 0$ | M_P_ENTRY |
| F | Change in MBA *minus* PhD change | Row D minus Row E | $\beta_M = 0$ | M_P_DIFF |
| G | MBA *vs.* Law at exit | EXIT = 1 & LAW = 0 & MBA = 1 *Vs.* EXIT = 1 & LAW = 1 & MBA = 0 | $\beta_M + \beta_{XM} - \beta_L - \beta_{XL} = 0$ | M_L_EXIT |
| H | MBA *vs.* Law at entry | EXIT = 0 & LAW = 0 & MBA = 1 *Vs.* EXIT = 0 & LAW = 1 & MBA = 0 | $\beta_M - \beta_L = 0$ | M_L_ENTRY |
| I | Change in MBA *minus* Law change | Row G minus Row H | $\beta_{XM} - \beta_{XL} = 0$ | M_L_DIF |

every case the control group provided lower scores than did program participants. The evidence, therefore, suggests that the program had a significant difference on perceived capabilities.

The hypotheses on rows C and D of Table 2 consider the control sample at entry versus exit and then the program sample at entry versus exit. As shown in Table 4, the results are quite striking. In only two cases are there significant differences in the *control* answers at entry versus exit and both are only significant at a 10% level (C_ENTRY_EXIT). In contrast, the *program* participants have significantly higher responses for 9 capabilities (EXIT). Note that if we compare the change in the control group (entry vs. exit) with the change in the program participants (entry vs. exit) we find a significantly larger gain for the latter in 12 of the 14 capabilities (EXIT_CONTROL).

Table 5 gives results for TI:GER program participants only. Holding constant field, there are significant differences in responses on exit from the responses at entry. All EXIT coefficients are positive, and 12 are significantly different from zero, implying that holding field constant, students perceived a significant improvement in their capabilities almost across the board.

This table also allows us to examine differences by field. On entry to the program the law students differed from PhD students in 6 capabilities (L_P_ENTRY); a positive sign indicates that the PhD students have a higher perceived capability. The MBA students differed from the entering PhD students in only two capabilities (M_P_ENTRY), and in both cases the PhD students had higher perceived capabilities. MBA and law students on entry differed across 5 capabilities (M_L_ENTRY), where all signs are negative indicating that the law students had higher perceived capabilities. Thus on entry the law students were most different. This difference continues on program exit. On exit law students are different from MBA students in 8 capabilities (M_L_EXIT) and for 5 of these the sign is positive indicating that MBA students had higher perceived capabilities. Law students were different from PhD students in 7 capabilities (L_P_EXIT), and for 5 of these, the sign is negative, indicating that the law students had lower perceived capabilities. MBA students differed from PhD students in only 3 capabilities (M_P_EXIT).

While there are differences in the impact of the program on perceived capabilities, it is interesting how few are significant; that is, while the different student groups had different perceived capabilities from one another on entry and on exit, the changes in capabilities were similar for each group. For the law students there is no significant difference from PhD students for 9 of the capabilities (L_P_DIF), and in each significant case the law student had smaller gains. For the MBA students there are only 2 significant differences from PhD students (M_P_DIF). The two capabilities in which the MBAs differ from the PhD students are quality control and identifying regulatory needs, and in both cases, the MBAs perceived a greater gain. For 5 capabilities, the MBA students perceived a greater impact of the program than did the law students (M_L_DIF). Among these are regulatory needs, identifying resources needed for commercialization, and identifying business opportunities.

## CHALLENGES TO PROGRAM DEVELOPMENT

The inherent complexity of integrative programs makes them somewhat difficult to develop. The

**TABLE 4**
**Ordered Logit Models: Capability of Performing Skills (Full Sample)**

| Dependent Variables | ASSESS BUS IMPACT LEGAL | ASSESS LEGAL EFECT BUS DEC | PLAN PROTECT IP | COMP ADV IP PROTECT | ID REG NEED | ID FIN SOURCE | ID MKT VIABLE | ID RES SUCCESS | ID BUS OPPS | EVAL OPPS & THREAT | EVAL BUS RISKS | ID CAR OPPS | WRITE TECH DOCS | QUAL CONTROL TECHNOLOGY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CONTROL | 1.092** | 0.537 | 0.331 | −0.724 | 0.842* | −0.148 | 0.86* | 1.016** | 0.314 | 0.667 | 0.347 | 0.316 | −0.034 | 0.987** |
| C_P_EXIT | −1.88** | −1.45** | −2.76*** | −2.22*** | −1.22* | −2.78*** | −1.97*** | 0.12 | −1.18* | −1.28* | −1.06 | −2.69*** | −0.83 | −0.93 |
| C_ENTRY_EXIT | −0.59 | −0.14 | −0.26 | −0.135 | −0.781 | −1.233* | −0.57 | 0.461 | −1.19* | −0.812 | −0.312 | −0.863 | 0.298 | −1.131 |
| EXIT | 2.29*** | 1.85*** | 2.83*** | 1.364** | 1.279* | 1.397** | 2.26*** | 1.362* | 0.305 | 1.137 | 1.094 | 2.147*** | 1.096 | 0.789 |
| EXIT_CONTROL | −2.88*** | −1.99** | −3.09*** | −1.499* | −2.06*** | −2.63*** | −2.83*** | −0.901 | −1.495* | −1.949** | −1.406* | −3.01*** | −0.798 | −1.92** |
| LAW | 2.55*** | 2.41*** | 0.402 | 0.035 | −0.36 | −0.355 | −0.124 | −0.209 | 0.185 | 0.256 | 0.677* | 0.077 | −1.951*** | −1.12*** |
| MBA | 0.509 | −0.124 | −0.139 | −0.11 | −1.116** | 0.386 | 0.789* | 0.292 | 0.916* | 0.666 | 0.916** | −0.138 | −1.30*** | −0.401 |
| EXIT_LAW | −0.572 | 0.124 | 0.353 | 0.225 | 0.471 | −0.68 | −0.887 | −0.46 | −0.171 | −0.669 | −0.744 | −1.39** | 0.161 | 0.236 |
| EXIT_MBA | −0.095 | 0.812 | −0.309 | 0.787 | 2.11*** | 0.603 | −0.624 | 0.258 | 0.51 | 0.096 | 0.17 | −0.73 | 0.306 | 0.889 |
| N | 217 | 217 | 217 | 217 | 206 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 217 |
| CHI SQ (11 DOF) | 102*** | 109*** | 81*** | 71*** | 46*** | 63*** | 54*** | 31*** | 25*** | 27*** | 27*** | 56*** | 51*** | 27*** |
| PSEUDO R SQ | 0.1926 | 0.187 | 0.1432 | 0.1296 | 0.0867 | 0.1103 | 0.1025 | 0.0635 | 0.0478 | 0.0546 | 0.0515 | 0.1121 | 0.091 | 0.0486 |

Note. Cohort effects are included in the model but did not result in significant values; They are omitted from the table for simplicity. Full model results can be obtained from the authors.

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

**TABLE 5**
**Ordered Logit Models: Capability of Performing Skills (TI:GER Participants Only)**

| Dependent Variables | ASSESS BUS IMPACT LEGAL | ASSESS LEGAL EFECT BUS DEC | PLAN PROTECT IP | COMP ADV IP PROTECT | ID REG NEED | ID FINANCE SOURCES | ID MKT VIABLE | ID RES SUCCESS | ID BUS OPPS | EVAL OPPS & THREAT | EVAL BUS RISKS | ID CAR OPPS | WRITE TECH DOCS | QUAL CONTROL TECHNOLOGY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXIT | 3.08*** | 3.68*** | 3.89*** | 2.22*** | 1.4* | 1.75** | 2.75*** | 1.94** | 0.53 | 1.36* | 1.58** | 2.31*** | 1.35* | 0.42 |
| L_P_ENTRY | 2.86*** | 4.17*** | 1.25** | 1.1** | −0.13 | −0.06 | 0.18 | −0.12 | 0.18 | 0.07 | 0.7 | 0.4 | −1.54*** | −0.98** |
| M_P_ENTRY | 0.34 | −0.64 | −0.43 | −0.57 | −1.1* | 0.18 | 0.68 | −0.14 | 0.48 | 0 | 0.8 | −0.06 | −1.6*** | −0.8 |
| M_L_ENTRY | −2.52*** | −4.81*** | −1.68*** | −1.67*** | −0.97* | 0.24 | 0.5 | −0.02 | 0.3 | −0.07 | 0.1 | −0.46 | −0.06 | 0.18 |
| M_L_EXIT | −1.78*** | −2.43*** | −1.8*** | −0.01 | 1.15* | 2.11*** | 1.02 | 1.53** | 1.23** | 0.9 | 0.75 | 0.53 | 0.39 | 1.43** |
| L_P_DIF | −1.5* | −1.67* | −0.95 | −0.85 | 0.13 | −1.19 | −1.53** | −1.2 | −0.52 | −0.9 | −1.25* | −1.62** | −0.28 | 0.47 |
| L_P_EXIT | 1.36** | 2.5*** | 0.3 | 0.25 | 0 | −1.25** | −1.35** | −1.32** | −0.34 | −0.83 | −0.55 | −1.22** | −1.82*** | −0.51 |
| M_P_EXIT | −0.42 | 0.07 | −1.5** | 0.24 | 1.15* | 0.86 | −0.33 | 0.21 | 0.89 | 0.07 | 0.2 | −0.69 | −1.43** | 0.92 |
| M_P_DIF | −0.76 | 0.71 | −1.07 | 0.81 | 2.25** | 0.68 | −1.01 | 0.35 | 0.41 | 0.07 | −0.6 | −0.63 | 0.17 | 1.72** |
| M_L_DIF | 0.74 | 2.38** | −0.12 | 1.66** | 2.12*** | 1.87** | 0.52 | 1.55* | 0.93 | 0.97 | 0.65 | 0.99 | 0.45 | 1.25 |
| N | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 154 |
| CHI SQ (9 DOF) | 84*** | 123*** | 77*** | 62*** | 40*** | 46*** | 48*** | 34*** | 14 | 24*** | 232*** | 38*** | 32*** | 21** |
| PSEUDO R SQ | 0.222 | 0.313 | 0.195 | 0.177 | 0.101 | 0.116 | 0.129 | 0.099 | 0.039 | 0.072 | 0.066 | 0.111 | 0.086 | 0.014 |

Note. Cohort effects are included in the model but did not result in significant values; They are omitted from the table for simplicity. Full model results can be obtained from the authors.

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

associated challenges range from issues that can be thought of as institutional (such as logistic challenges of cross-campus collaboration or obtaining "buy-in" from administrators and faculty across academic units) to programmatic and pedagogical issues that stem from the goals, culture, and language of students pursuing degrees in different disciplines. In this section, we highlight some issues and lessons learned in the nearly 2 decades it took to develop the program as it exists today.

**Institutional Factors**

TI:GER was developed based on two programs started by Marie Thursby at Purdue University, the Technology Transfer Initiative, and the Innovation Realization Lab.[3] The impetus for the Technology Transfer Initiative was a visit by Dr. Alan Peterson in the early 1990s in which he discussed his concerns that education in technology commercialization was limited because of the failure of universities to examine relevant issues from a coordinated interdisciplinary perspective. In particular, while commercialization of new technologies depends on scientific, legal, economic, business, and political factors, academic approaches at the time were formulated primarily within (rather than among) disciplines. The question Dr. Peterson put to the university was whether there was interest in seed funding from his foundation to develop a multidisciplinary program to conduct research and educational programs to address this need. A point of emphasis was that program outcomes should be student-oriented and of national and global benefit (rather than a local economic development focus).

The Technology Transfer Initiative was founded in 1993, and for the next 9 years, funded small grants for faculty across the Schools of Agriculture, Engineering, Science, and Management. One of these grants supported teams of MBA and electrical engineering PhD students to explore commercial applications for research in the engineering lab. This team served as a pilot for the later Innovation Realization Lab. As does TI:GER, the Lab combined team activities focused on technology commercialization with coursework and research on the innovation process. The major difference in the two is that the Lab focused more on the management, rather than legal aspects of innovation, since neither faculty nor students from a law school were involved. Plans to expand the legal aspects began when Thursby moved to Georgia Tech in 2001.

Central administration "buy-in" and foundation funding targeted toward multidisciplinary education contributed to the development of all three programs. The Innovation Realization Lab and TI:GER were both supported by a combination of funding from the Alan and Mildred Peterson Foundation, the National Science Foundation Integrative Graduate Education and Research Training (IGERT) Program, and the universities. The foundations' funds supported doctoral student participation and university funds supported the MBA students and staff. Law students have not received financial support, an issue we revisit below.

While external funding is not absolutely necessary, it does serve as a catalyst for cross-school collaboration, and it may be necessary for programs as comprehensive as TI:GER. Since the TI:GER core includes modules which are team taught, faculty participation typically requires either overload payment as an incentive or fractional course credit (which the administrative unit allows to accumulate for release time). Because the culture in engineering and science PhD programs is for students to work full time in their advisor's lab, partial or full student funding is an important incentive mechanism for obtaining advisor "buy-in" for their students to participate. The prestige of the NSF IGERT awards was a significant attraction on the PhD side. As PhD students and advisors gained experience with the program, the prestige factor has become less important, so that as the program moves forward with university and private foundation funding, interest on the PhD side remains substantial. Other institutional barriers include cross-registration of classes and logistics. These can be difficult, and, while the solutions are somewhat straightforward, they require administration "buy-in." Student participation is most easily arranged when courses are cross-listed and when academic units receive credit for teaching credit hours (as opposed to a model where units receive credit only for teaching majors in a discipline).

The TI:GER program spans both disciplinary and university boundaries. Indeed the partnership between the public university Georgia Tech and the private Emory University would have been more difficult without strong pre-existing connections between these institutions. Of course for universities with law, business, and science or engineering PhD programs in house, program implementation should be easier; anecdotal evidence suggests, however, that in many universities there are cultural barriers across these disciplines within the

[3] For benchmarking of other programs see Thursby (2005).

university. There are also obvious barriers for universities without close geographical proximity to one of the crucial disciplines. This was a problem with integrating law into the Purdue program. For such cases, collaboration with external business partners, while it does not provide the richness of JD students on the teams, provides content for the courses and team advisors. This also perhaps suggests the merits of cross-university networks promoted by various federal granting agencies.

### Programmatic and Pedagogical Factors

A number of challenges stem from different paradigms across the degree programs involved in TI:GER. As mentioned above, PhD programs typically provide students with stipends as well as tuition. Increasingly MBA programs compete for the best students with funding offers, but, in general, financial support for students is less common among professional programs. The majority of the Emory law students, for example, take out loans to support their education. These funding differences tend to cause equity issues for the teams.

Different grading structures and pedagogical styles also pose challenges. While it is rare for PhD students to earn grades of B or C, MBA and JD classes are graded on strict curves. Additionally job placement for PhD students depends almost entirely on research performance, while JD placement depends primarily on class ranking (and therefore is a function of grades). This challenge can be addressed by either pass/fail grading, or by taking the differential grading curves across fields into account in final grades.

A more fundamental problem is the difference in student motivations and learning styles (Fleming et al., 2005a,b). It is well known that scientists (regardless of area) tend to doggedly pursue the origins and implications of various phenomena and are as motivated by the process of "puzzle solving" as they are by financial returns (Hagstrom, 1965; Thursby, Thursby, & Muhkerjee, 2007). By contrast, "logic" of law is much more focused on role of precedents, and business professionals are much more focused on financial implications of various phenomena. Our early focus groups highlighted student frustration in dealing with these differences within their teams. We now emphasize understanding and working effectively with these differences the first few weeks of the program. There is a mandatory TI:GER retreat focused on team-building skills.

Pedagogical delivery that simultaneously engages all three student groups is also critical. With students from such disparate backgrounds in the same program, many will have little knowledge of fundamental principles in the other disciplines. Science and engineering students are unlikely to have taken courses in law, economics, or business. In a similar way, the law students may not have studied business or economics, and business students are unlikely to have taken law courses. This presents challenges in both course delivery and curriculum materials. One solution is to require students to take background courses in the other disciplines but, as outlined earlier, this is rarely feasible for graduate students. The approach we have taken, which appears to be successful, is to develop our own course materials and structure classes so that they involve team exercises. For materials, the Kauffman Foundation funded a project in which the TI:GER faculty wrote a text, used in Fundamentals of Innovation I and II, which distills current research in each of the core topics at a level accessible to all the students (Libecap & Thursby, 2008). For class structure, the key is delivery that informs those with limited backgrounds, while avoiding boring those with in-depth knowledge. Thus, our classes tend to focus on content delivery for an hour or so, after which key concepts are applied to an in-class exercise in the context of team projects. At the end of class, teams are asked to report on how they applied the concept. Exercises are structured to encourage students from each discipline to participate in all team projects, and course grades include credit assigned by team members.

## CONCLUSION

Students destined for innovation-related careers typically prepare by obtaining one or more graduate degrees, obtaining research and/or professional credentials at the master's or doctoral level. In the case of scientists and engineers, the PhD is the most advanced technical degree, and in the case of business or legal professionals the MBA and the JD are the terminal degrees. Improving the ability of businesses (large and small) to succeed requires these professionals to better understand how to leverage technology, business, and law for innovation. But this requires an understanding of knowledge at the interface of very different disciplines. Since much of this knowledge is tacit, an integrated team-based approach is needed.

The fact that it took more than a decade to develop the TI:GER program as it is today makes it clear that the challenges of developing such an integrative program are significant. As emphasized in the last section, as well as a recent National Academies study of interdisciplinary program challenges (Committee on Facilitating Interdisciplinary Research, 2004), it is necessary to break down a host of barriers, both institutional and cultural. Nonetheless, surveys of R&D intensive companies indicate that it is crucial for the professionals they hire to understand the multidisciplinary aspects of technology commercialization.

The program described herein brings PhD, MBA, and JD students together in a formal program focused on issues in technology commercialization in the context of the science and engineering students' research. While the primary skills taught in their disciplinary programs vary, some capabilities will be needed by all in future careers in innovation. At some point, all these students need to be able to identify market opportunities for inventions. As is apparent from growing public policy concerns, it is also important that those involved with business and intellectual property strategy understand the implications of their decisions, not only for potential success of current inventions, but also for the freedom of future scientists and engineers to build on these inventions (Rai & Eisenberg, 2003; Thursby & Thursby, 2003). For all, communication and networking skills are important (Perry-Smith & Vincent, 2008).

Although our data are self-reported perceptions, it is clear from our empirical analysis that the program described has had significant effects on student perceptions of their ability to perform within an innovation-intensive business environment. Those changes were not observed in a control group, and to our knowledge this is one of the few studies of entrepreneurship education to identify these changes as treatment effects (rather than selection). Both on entry to and exit from the program, we find significant differences by field in perceived capabilities. There are, however, few significant differences by field in the perceived gains between entry and exit.

The environment these students are involved in is somewhat distinct from entrepreneurship education and research in the context of small business creation. That is, the program philosophy is that many of the skills needed for successful innovation apply regardless of firm size. Thus, we have not focused on prescriptions for small business education, but to the extent that Baumol (2004) and the U.S. Small Business Administration (2003) are correct that small business innovation is more likely to be linked to scientific research, this suggests that our approach is appropriate.

Our empirical data on program graduates is limited, in part because of challenges in tracking graduates, but also because the PhD degree completion can take 5–6 years. Nonetheless, we have qualitative feedback from some of the graduates. The majority of the MBA graduates work for Fortune 500 companies. One student noted, "communication between parties of different backgrounds . . . is critical in my area of work, and TI:GER strengthened these skills 100 fold." Another MBA graduate reports, "although I work for a big company, the holistic experience of TI:GER is proving very valuable." We know of one of our MBA graduates began a technology start-up with a PhD engineer immediately upon TI:GER graduation, and several others plan to work in start-ups once they gain additional industry experience.

Of the PhD graduates covered by our data, we know of 7 who took jobs in either start-up or consulting companies as business development scientists. The PhD graduates report that the TI:GER program "provided both business and IP perspectives on my research which the Engineering program would have otherwise ignored," "had a tremendous impact on the way I think about doing research . . . in my job at NASA I apply these skills almost daily," and finally, "I gained a better appreciation for how to reconcile academic rigor with industrial need and how to properly market and adopt my research to different audiences." Over 90% of the law graduates work for established law firms. Several students have reported that they were able to earn more interesting initial assignments than other new grads, and they attribute this to their TI:GER experience. A law graduate working at the U.S. Department of Justice said, "understanding technology industries and businesses is critical to our investigations . . . I feel I better understand the startup process because of TI:GER."

Gaining an understanding of our graduates' performance as well as their opinions after they have been in their jobs for several years is an area of future research. We also hope to obtain information from employers on how TI:GER graduates are meeting their needs in order to enhance our future curriculum development. Finally, an issue not addressed here is the extent to which the TI:GER research goals have been met. How scientific research is affected by commercialization activities is an issue of growing concern in policy circles and one we hope to address in the future (Thursby & Thursby, 2009).

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